Coal matrix shrinkage and its effects on cleat porosity, permeability and late life coal behaviour

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Introduction

In Australia, coal seam gas (CSG) has become an integral part of the gas industry, particularly in Queensland, comprising over 95% of the gas produced and over 99% of the remaining proved and probable gas. Coal is a complex porous media developed with a dual porosity in which micropores account for the primary porosity and natural fracture (cleat) network provides the pathway for fluid flow. Moreover, gas adsorption and desorption processes generally result in coal matrix swelling and shrinkage (refer to the sorption-induced strain), which can potentially impact cleat apertures and, consequently, the permeability of coal. Therefore, this project is to study the effects of methane pressure on matrix shrinkage and cleat changes and attempt to gain fundamental new knowledge on the coal properties that are affecting shrinkage.

Objectives

- Develop new capability for CT scanning coal samples exposed to CH_4 at various pressures, and test a wide range of coal samples;
- Characterise internal local matrix shrinkage with varying macerals and minerals during step-by-step CH_4 depressurization process;
- Observe and measure the cleat changes (such as aperture, length and distribution) and determine the effect of coal matrix shrinkage on the cleat changes.

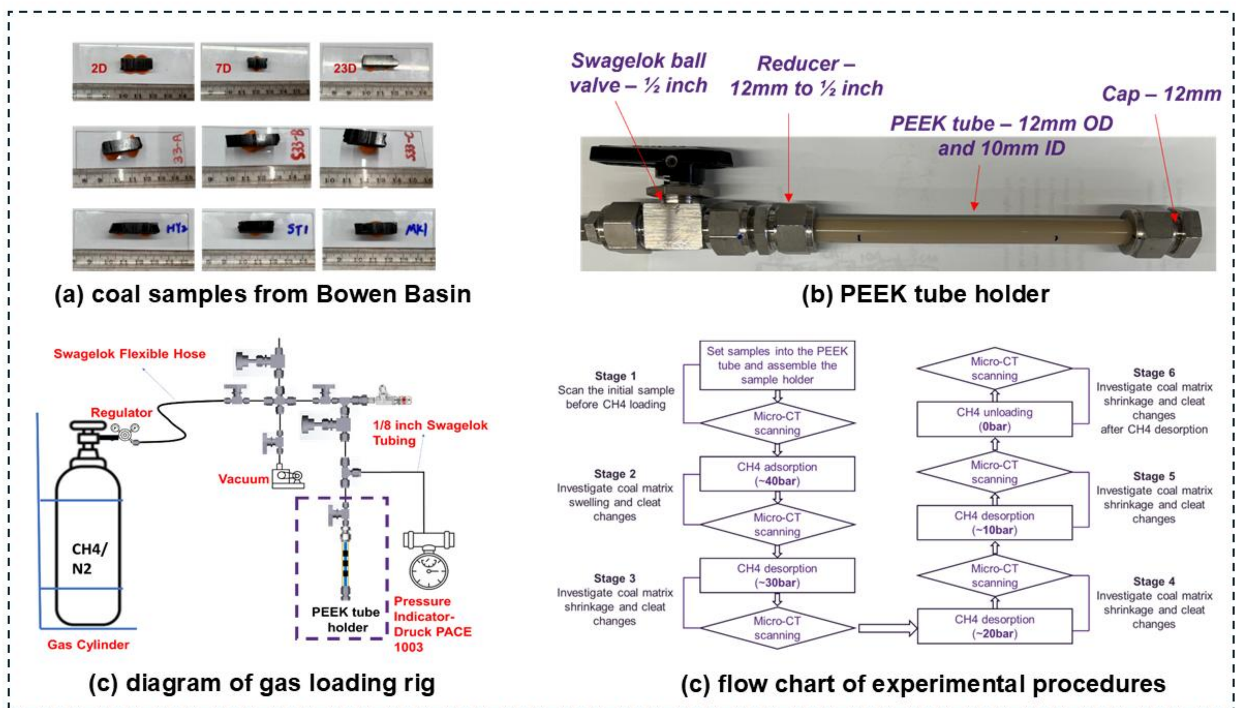

Figure 1: Samples and methodology.

Method

Sample preparation

Small representative rectangle coal blocks were cut off and shaped to the dimension of 20-30 mm length, ~7 mm width and ~7 mm height. Then one of the faces with orientation perpendicular to the bedding plane was well polished (Figure 1a).

X-ray transparent cell and gas loading rig

The X-ray transparent cell (XTC) was prepared from a 12 mm outer diameter PEEK tube with an internal diameter of 10 mm. The ends of the tube were closed using Swagelok fittings and taps, allowing for the injection, release, or sealing of pressurized gases within the tube by simply opening or closing the taps polished (Figure 1b). For loading methane into the XTC and subsequent pressure monitoring, an experimental rig was set up (Figure 1c).

CH_4 adsorption/desorption and micro-CT scanning

As shown in Figure 1d, for stage 1, coal samples were assembled into the XTC and then scanned by CT facility (Comet Yxlon FF35 CT, CAI) to get the original coal matrix/cleats before CH_4 loading. For stage 2, approximately 40 bar CH_4 was injected into the XTC and let coal adsorbed CH_4 for 10-14 days until reaching equilibrium state. Then the XTC with ball valve closed was disconnected from the loading rig and taken to do CT scan to get coal matrix swelling characteristics. From stage 3 to stage 6, depressurization CH_4 desorption experiments were conducted at intervals of 10 bar, and then coal samples under equilibrium state at different pressures were scanned separately. During step-by-step CH_4 desorption process, coal matrix shrinkage behaviour and cleat changes were investigated and compared.

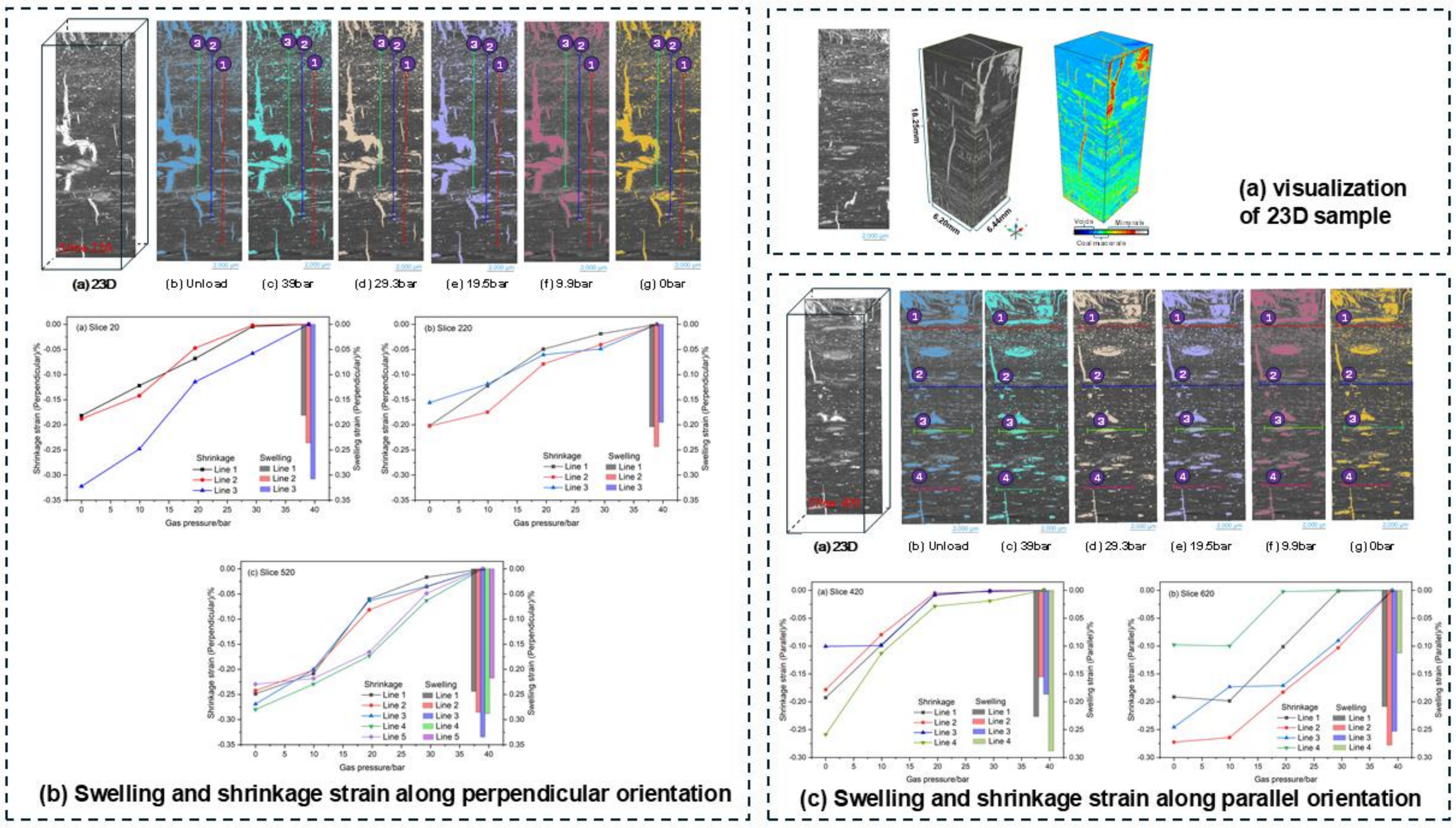

Figure 2: Sorption-induced strain on perpendicular to the bedding planes (perpendicular orientation) and parallel to the bedding planes (parallel orientation).

Results

Sorption-induced strain (perpendicular vs. parallel)

CH_4 adsorption-induced swelling and desorption-induced shrinkage are quantitatively measured using the mineral tracking method. Based on the properties of CT scanning, the sorption-induced strain can be measured in both perpendicular and parallel orientations.

Perpendicular orientation

The matrix swelling strain on perpendicular orientation is 0.26% when the equilibrium pressure achieves 39 bar, and the shrinkage strain is -0.24% during step-by-step depressurizing from 39 bar to 0bar. This indicates that 23D coal has excellent elastic properties. Moreover, it appears that coal matrix shrinks non-linearly from 39 bar to 0 bar, showing a low shrinkage strain in high pressure range (dropping from 39 bar to 29.3 bar) and a more severe shrinkage strain in low-pressure range (dropping from 19.5 bar to 9.9 bar).

Parallel orientation

The swelling strain on parallel orientation is only 0.19% when the equilibrium pressure achieves 39 bar, and the shrinkage strain is -0.16% during step-by-step depressurizing from 39 bar to 0bar. For 23D sample, the sorption-strain of coal matrix on perpendicular orientation is about 1.3-1.5 times higher than that on parallel orientation. Meanwhile, different regions composed of different maceral bands or different macerals and minerals demonstrate more heterogeneous sorption-strain characteristics.

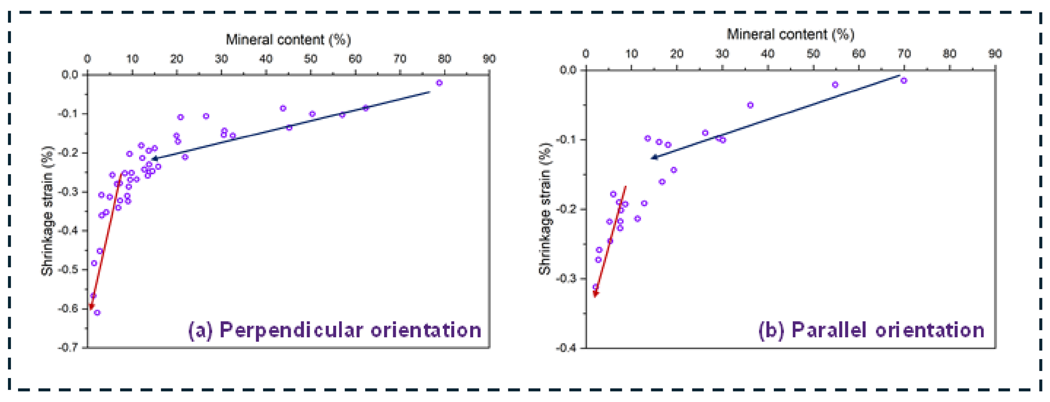

Figure 3: Relationship between mineral content and matrix shrinkage strain.

How minerals influence matrix shrinkage?

- For regions with high mineral content (>10%), the matrix shrinkage strain shows a slow increasing trend with mineral content decreasing.
- For regions with low mineral content (<10%), the matrix shrinkage strain steeply increases as mineral content decreases.

High content minerals or mineral layers may act as 'proppant' to reduce the matrix shrinkage ability. Moreover, the coal matrix is closer to the shrinkage ability of coal macerals when the mineral content is extremely low.

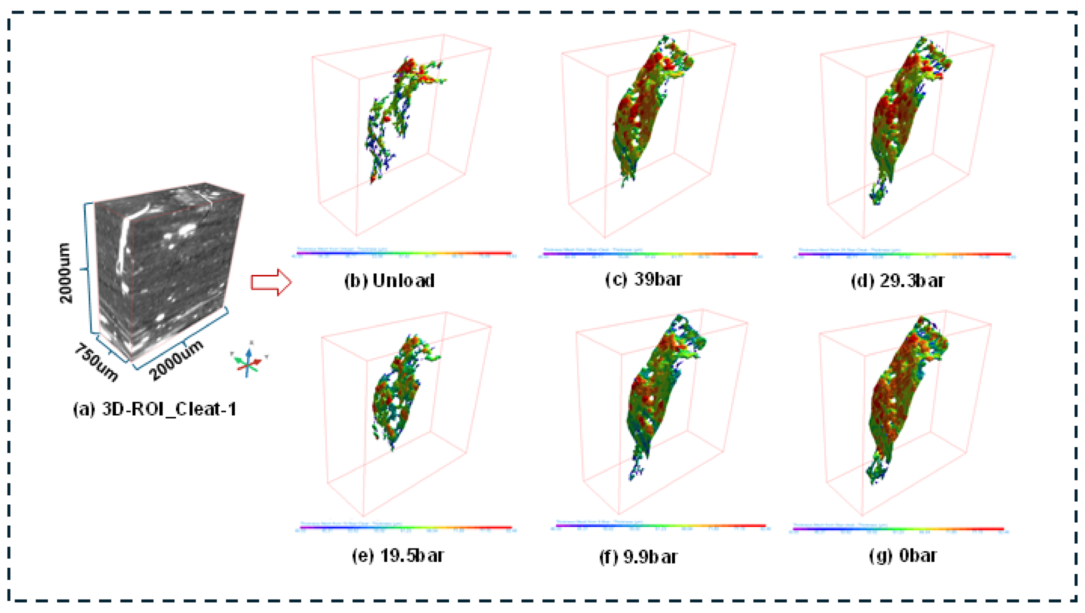

Figure 4: 3D distribution and changes of cleat.

Effect of matrix shrinkage on cleat changes

- In 23D sample, cleat-1 enlarges with the injection of high-pressure methane (from unload to 39 bar), resulting not only in an increase in aperture but also in length and distribution area.
- When the gas pressure drops to 0 bar step-by-step, the aperture, length, and distribution area of cleat-1 are slightly enlarged simultaneously (except for 19.5bar).

It was expected that the enlarged cleats may be closed or narrowed when gas is gradually desorbed from cleats and pores. However, this may be related to the coal matrix shrinkage behaviour during gas desorption and cleat development or distribution.

Conclusions

- New capability by combining an X-ray transparent cell with micro-CT scanning is developed to visualise and quantify the sorption-induced strain and cleat changes in coals.
- Gas sorption-induced strain of coal in the perpendicular orientation is greater than in the parallel orientation.
- High content minerals or mineral layers may act as 'proppant' or 'aggregates' to reduce the matrix shrinkage ability. When the mineral content is extremely low, the coal matrix shrinkage is mainly dominated by different coal macerals.
- The interaction between pore pressure and matrix shrinkage force plays an important role in the enlargement and closure of cleats.

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